PATENT

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APPLICATION FOR UNITED STATES LETTERS PATENT

for

DOWNHOLE OILFIELD EROSION PROTECTION OF A JET PUMP THROAT BY OPERATING THE JET PUMP IN CAVITATION MODE

by

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BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to the cleaning of wellbores in the field of oil and gas recovery. More particularly, this invention relates to a device adapted to improve the erosion performance of components utilized in the removal of solid particulate matter from a well.

Description of the Related Art

[0002] In the oil and gas industry, wellbores often become plugged with sand, filter cake, or other hard particulate solids, which need to be removed periodically to improve oil production. Prior art methods for cleaning the wellbore and the removal of these particulate solids include pumping a fluid from the surface to the area to be cleaned. To effectively clean the solids from the wellbore, the pumped fluids must return to surface, thereby establishing circulation. Therefore, the bottom of the hole circulating pressure must be high enough to support circulation but low enough to prevent leak off into the reservoir. In addition, the fluid velocity and rheological properties must support solids suspension and transport.

[0003] It is known that the bottom hole pressure of a wellbore declines as the reservoir matures, thereby complicating the wellbore cleanout. For example, if the fluid being pumped into the wellbore exits the work string (e.g., coiled tubing) at an excessive pressure, the fluid may enter the formation instead of returning to the surface with the sand particulates.

[0004] To overcome this problem, it is known to utilize gasification (e.g., by the addition of nitrogen to the fluid) to decrease the hydrostatic pressure in the wellbore. Thus, the fluid may be pumped at reduced bottom hole pressures and circulation through the wellbore may be restored to transport the particulates to the surface. However, over time, the reservoir pressure may decline to a point whereby gasification fails to result in consistent circulation of fluid to effectively remove the particulates.

[0005] Reverse circulating is another method commonly used to increase the transport velocity of the fluid, especially when employing small diameter tubing in large wellbores.

[0006] Yet another prior art method of removing the particulate solids in the wellbore where the bottomhole circulating pressure is a concern employs a jet pump. In the oil and gas industry, the jet pump concept often is used to draw wellbore fluids into a closed circuit hydraulic stream and return the wellbore fluid to the surface. This procedure is generally performed in wells that have very low bottom hole pressures, where the wellbore fluids cannot be transported easily to the surface using other nitrogen lift methodologies to lighten the hydrostatic head of the well. As described in U.S. Patent No. 5,033,545 to Sudol, issued July 23, 1991, incorporated by reference herein in its entirety, the jet pump is designed such that well fluids and solids enter the jet pump at the bottom hole pressure (BHP). The jet pump then increases the fluid pressure as it pumps the fluids up the work string with the solid particulates entrained in the fluids. Thus circulation is facilitated, as the circulation no longer depends on BHP alone.

[0007] FIG. 1 shows an exemplary prior art jet pump apparatus and method for effectively removing particulates such as sand from within a wellbore using production tubing. With reference to FIG. 1, a power fluid (arrows PF) is admitted under pressure to an annular space between an outer pump casing 12 and the jet pump device body 5. The annular space is closed off at its lower end. In the general installation shown in FIG. 1, tubing string 8 is attached at the top of the jet pump device body 5.

[0008] The jet pump includes one or several power fluid inlet ports 9 for admitting power fluid to the main nozzle 1 of the pump. The main nozzle 1 discharges into a throat area 100 of the pump assembly. The jet pump also includes a well fluids inlet port 7 for admitting well fluids, or a mixture of fluids and solids, to fluid passages in fluid communication with throat area 100. Power fluid, under high pressure in the annular space, flows in the direction of the arrows PF through the power fluid inlet port 9 into the main nozzle 1. The main nozzle 1 jets the power fluid into the high impact area 2 of the throat area 100.

[0009] Well fluids and solids flow under formation pressure through the well fluids inlet port 7. The well fluids and solids then flow in the direction of the arrows WF and into the high impact area 2 of the throat area 100. The well fluids and solids violently mix with the power fluid in the throat area 100, particularly in the high impact area 2. The returns (arrows R), comprised of power fluid, well fluids and solids, then move through the throat to production tubing 8, which extends to the production equipment at the surface.

[0010] The jet pump also is particularly well-suited for use with a coiled tubing string inside a coiled tubing string, or "coil-in-coil tubing" (CCT), as described in U.S.

Pat. No. 5,638,904 by Misselbrook et al., issued June 17, 1997, incorporated by reference herein in its entirety. The power fluid is pumped down the inner coiled tubing string, and the return fluid stream, which is comprised of a mixture of power fluid and well fluids and solids, is taken up the coiled tubing-coiled tubing annulus.

[0011] The following is a simplified summary of the operation of this prior art apparatus and method. With reference to FIG. 2, a jet pump 5 is shown within a wellbore. The jet pump 5 is attached to the bottom of CCT (not shown) via housing 6. In operation, the jet pump closed circuit hydraulic stream generally begins with power fluid, preferably water or brine, being injected into a pipe with one end at the surface, preferably the inner coiled tubing string (from left to right in FIG. 2). The power fluid then travels down the pipe to the wellbore, goes through jet pump 5 to entrain wellbore fluid, and finally returns to surface through an alternate pipe or other closed path (pipe-pipe annulus), preferably the coiled tubing-coiled tubing annulus.

[0012] The power fluid enters the lower end of jet pump 5 in the direction shown by the arrows PF (from right to left in FIG. 2). As the power fluid passes through nozzle 1 at nozzle exit 3, the velocity of the power fluid increases significantly, creating a jet stream. The jet pump itself acts like a venturi by taking the high pressure power fluid (pumped from surface) and increasing the power fluid's velocity via the nozzle 1. This increased velocity reduces the pressure in the power fluid stream, which enables the low pressure power fluid stream to draw in some portion of the well fluids and solids (indicated by arrows WF) at well fluids inlet port 7. The high-velocity combined fluid stream, which may contain both fluids and solids, then enters the entrance end of the diffuser or throat area 100. As the combined fluid stream (arrow R)

continues to travel upward through the throat area 100, the diameter of the throat increases, the velocity of the fluid decreases, and the fluid pressure increases. This recovered fluid pressure drives the return fluid stream (arrow R) back to the surface, overcoming the hydrostatic head.

[0013] If the jet pump is used to draw in sand or other well solids as part of the wellbore fluids, severe erosion in the throat area is observed, as the high velocity power fluid stream causes the solids to impinge, scrape, and abrade the throat. As the solids initially are drawn into the high velocity power fluid stream, the velocity of the solids-ladened fluid does not yet match the velocity of the power fluid stream. The solids-ladened fluids tend to remain on the periphery of the power fluid stream, as shown in FIG. 3, where they are more likely to have high-velocity impact with the entrance section 10 of the throat 100. It has been determined that in many applications, this causes excessive erosion in the high impact area 2.

[0014] As a practical matter, poor erosion performance translates into operational inefficiencies, as more frequent trips out of and into hole are required to replace the excessively eroded components.

[0015] Erosion of the downhole tools may be exasperated when cleaning particulates from deeper wells. Deeper wells produce additional challenges for the above-referenced procedure, as the deeper wells have increased hydrostatic pressure and increased friction pressure. Thus, the coiled tubing operation must incorporate higher pump output pressure and higher jet velocities in the nozzle and throat. For example, it is not uncommon for an 8600-foot well to have a bottom hole pressure of 1000 pounds per square inch, causing the flow velocity through the throat to be between

200 and 600 feet per second. These higher particle-laden jet velocities increase the erosion rate in the throat.

[0016] It is also known in the prior art to decrease the erosion of the components of downhole tools by manufacturing the components of various materials, such as ceramics like Yttria stabilized zirconia, or 6% submicron tungsten carbide. However, these prior art methods fail to provide the desired level of erosion performance and may not be economically feasible with deeper wells (and the concomitant increased jetting velocities), as excessive erosion still may result.

[0017] Thus, there is a need for a method for improving erosion resistance (i.e., decreasing the erosion) of components used in the cleaning of a wellbore, such as throats or diffusers utilized downhole, when the components are exposed to high velocity sand/fluid slurries. The method according to one embodiment of the invention resists erosion associated with the high velocity jets of solids-ladened fluid slurries generated when removing particulate solids, such as sand, from the wellbore during well intervention or workover. Further, the method of a preferred embodiment improves longevity of components for downhole jet pumps and reduces the relative frequency of trips in and out of hole for worn component replacement.

SUMMARY OF THE INVENTION

[0018] The invention relates to methods of improving the erosion resistance (i.e., decreasing the erosion) of components - for example, throats and diffusers - of downhole tools used in the removal of particulate solids from the wellbore.

[0019] The preferred method comprises operating a jet pump in a condition known as cavitation when drawing in sand or other wellbore solids, in order to decrease the erosive effect of drawing the solids into the jet pump. When a jet pump is operated in cavitation mode, the pumped power fluid stream velocity is increased to a point where the power fluid pressure becomes very low or near absolute zero—lower than the vapor pressure of the fluid itself—where the fluid stream exits the nozzle. As the power fluid exits the nozzle at this high velocity, the ultra low fluid pressure causes the power fluid to create cavitation vapor bubbles, which quickly form and then collapse as the power fluid is recaptured by the throat. This action is extremely violent and causes severe mixing of the power fluid and the wellbore fluids being drawn in. The severe mixing action forces the sand particles or other solids to be fully immersed in the fluid stream and lessens the sand particles' exposure to the throat surface, thereby reducing erosion of the throat.

[0020] One embodiment of the invention is directed to a method of protecting a jet pump throat from downhole erosion comprising the steps of positioning a jet pump in a wellbore, pumping a power fluid through the jet pump at a sufficient velocity to cause the power fluid pressure in the area between the nozzle and throat to be less than or equal to the power fluid vapor pressure, and drawing solids-ladened wellbore fluid into the jet pump and mixing the wellbore fluid with the power fluid. Another embodiment describes a method of removing solids from a wellbore comprising the steps of providing a jet pump in a wellbore, pumping a power fluid through the jet pump at a sufficient velocity to create cavitation vapor bubbles in the power fluid in the throat, and drawing solids from the wellbore through the well fluid inlet ports and

mixing the solids with the cavitation vapor bubbles of the power fluid. Yet another embodiment describes a method of removing solids from a wellbore comprising the steps of pumping a power fluid to a downhole jet pump, drawing wellbore solids into the jet pump and mixing the solids with the power fluid while the fluid pressure of the power fluid is less than or equal to the vapor pressure of the power fluid, and transporting the solids-ladened mixture through the throat of the jet pump and out of the wellbore.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] FIG. 1 shows a jet pump known in the prior art.

[0022] FIG. 2 shows a jet pump known in the prior art attached to coil-in-coil tubing.

[0023] FIG. 3 illustrates the erosive effects of operating a jet pump according to prior art methods.

[0024] FIG. 4 illustrates the operation of a jet pump in the cavitation mode in accordance with one embodiment of the invention.

[0025] While the invention is susceptible to various modifications and alternative forms, a specific embodiment has been shown by way of example in the drawings and will be described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the intention is to cover all modifications, equivalents and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

[0026] An illustrative embodiment of the invention is described below as it might be employed in the oil and gas recovery operation. In the interest of clarity, not all features of an actual implementation are described in this specification. It will of course be appreciated that in the development of any such actual embodiment, numerous implementation-specific decisions must be made to achieve the developers' specific goals, which will vary from one implementation to another. Moreover, it will be appreciated that such a development effort might be complex and time-consuming, but would nevertheless be a routine undertaking for those of ordinary skill in the art having the benefit of this disclosure. Further aspects and advantages of the various embodiments of the invention will become apparent from consideration of the following description and drawings.

[0027] Embodiments of the invention will now be described with reference to the accompanying FIG. 4. Dimensions described or shown are intended for example only, as the invention disclosed herein is not limited thereto. The invention is particularly well-suited for use with a downhole jet pump attached to coil-in-coil tubing. Referring to FIG. 4, the entrance section 10 of a throat 100 is shown. The throat 100 may be comprised of any hardened material suitable for downhole use, such as 6% cobalt tungsten carbide. Flow of fluid during the cleanout procedure is from right to left (i.e. the surface equipment is on the left, and the downhole obstruction being removed from the wellbore is on the right). A main nozzle 1 also is shown. By way of

example, the inner diameter of the nozzle preferably is in the range of about 0.060 inch to 0.125 inch.

[0028] In operation (as illustrated generally in FIGS. 1 and 2), the high-velocity fluid with sand or other solid particulates ultimately enters the entrance section 10 of the throat 100. As shown schematically in FIG. 4, operating the jet pump in cavitation mode causes solids to enter the center of the throat passage, suspended in a mixture, and greatly reduces the degree of erosional solids contact with the high impact area 2.

[0029] First, the power fluid (arrows PF)—preferably brine but alternatively water, friction reduced water, gelled water, diesel, hydraulic oil, or the like—enters the nozzle 1 at high static pressure and low velocity. Second, the power fluid (arrows PF) in a preferred embodiment exits the nozzle 1 at the nozzle exit 3 at high velocity and very low pressure—near absolute zero and lower than the vapor pressure of the power fluid itself. This ultra low fluid pressure at the nozzle exit 3 causes the power fluid to vaporize and the creation of cavitation vapor bubbles. Third, solids-ladened well fluids (arrows WF) enter the wellbore under formation pressure at well fluids inlet 7. As the well fluids and solids enter the power fluid stream, the power fluid velocity decreases and the static pressure increases, thereby causing the cavitation vapor bubbles to recollapse as the power fluid is recaptured by the throat 100. The cavitation vapor bubble formation-and-recollapse action is extremely violent and causes severe mixing of the power fluid (arrows PF) and the wellbore fluids (arrows WF) being drawn in. As depicted schematically in FIG. 4, the severe mixing action forces the solids to be fully immersed in the combined return fluid stream (arrow R). This full immersion of the solids causes the solids to enter the center of the throat passage, thereby lessening the

solids' direct contact with the internal walls of the throat entrance at high impact area 2. As a result, erosion of the throat 100 is reduced. Operating the jet pump using the cavitation method of the present invention is thus an improvement over prior art methods having no or inferior erosion resistance.

[0030] Operating a jet pump in cavitation mode provides a maximum limit on the wellbore flow rate. Maximum wellbore flow rate is a function of multiple parameters, including nozzle diameter, throat diameter, and wellbore pressure, as well as pump pressure and pump rate. After achieving the maximum wellbore flow rate, an additional increase in the pump rate achieves no incremental increase in returns at the surface. Therefore, whether a jet pump is operating in cavitation mode downhole may be determined at the surface by the presence of further increases in pump pressure and pump rate without achieving more suction or an increase in returns.

[0031] For example, initially the jet pump may operate at a pump rate of 60 liters per minute (lpm), with fluid returning to the surface at the same rate of 60 lpm. As the pump rate is increased, e.g. to 61 lpm, the fluid return rate may increase as more wellbore fluid is drawn into the return fluid stream, e.g. to 62 lpm. If the pump rate is increased further, e.g. to 70 lpm, the fluid return rate may increase further, e.g. to 90 lpm. The difference between the fluid return rate (out of system) of 90 lpm and the pump rate (into system) of 70 lpm is 20 lpm, which indicates that the system yields an additional 20 lpm in suction. Now, if the pump rate is increased further to 80 lpm, and the fluid return rate is 100 lpm, the net system increase would remain at 20 lpm in suction. Because further increases in pump rate do not achieve an increase in suction or

fluid returns, the system is operating at its maximum, and it may be deduced from the surface that the jet pump is operating in cavitation mode downhole.

[0032] Experimental results have been obtained for this embodiment of the present invention. A test was set up wherein a jet pump was operated in cavitation mode to draw a sand/water slurry from a simulated wellbore. The erosion rate of the throat, which is proportional to the cross-sectional area of throat removed per volume of sand removed from the well, was approximately 50% of normal wear when the jet pump is not operated in cavitation mode. Representative experimental data are provided in TABLE 1 below.

TABLE 1
Experimental Data

Measured Parameter	Test # 034 7/10/03	Test # 044 10/9/03	Test # 044 (continued) 10/15/03
Setup			
Nozzle diameter (in)	0.070	0.070	0.070
Throat diameter (in)	0.102	0.102	0.102
Flow Rates			
Nozzle flow rate (LPM)	44	51	51
Diffuser flow rate (LPM)	50	67	67
Wellbore flow rate (LPM)	6	16 (max)	16 (max)
Pressures			
Nozzle pressure (psi)	7600	9500	9500
Diffuser pressure* (psi)	4500	4500	4500
Wellbore pressure (psi)	1000	1000	1000
Suction pressure (estimated psi)	900	0 (cavitation)	0 (cavitation)
Sand Removal Results			
Volume of sand removed "SR" (in^3)	6200	5750	13000
Worn throat diameter (in)	0.113	0.107	0.115
Cross sectional area of throat removed "Area" (in^2)	0.00186	0.00082	0.00222
Ratio SR/Area x 1000 (in)	**3330**	**7000**	**5860**
Comments	Low suction flow rate	Pump at cavitation to maximize sand intake	Realize cavitation erosion benefit
* Diffuser pressure of 4500 psi is required for operations at 9,000 feet total vertical depth (TVD).			

[0033] Sand was removed from a simulated well of 9,000-foot total vertical depth in conventional and cavitation modes of operation. Simulated well conditions included a jet pump assembly with a nozzle of 0.070-inch diameter, a throat of 0.102-inch diameter, and a throat configuration having a 5-micron thick layer of polycrystalline diamond (PCD).

[0034] The erosion of the throat 100 using the cavitation jet pump operational mode of the present invention was compared to the erosion of the throat 100 using the

conventional jet pump operational mode. Operating the jet pump in cavitation mode allowed sand removal for a longer period than conventionally. The experimental data suggests a 50% to 150% improvement in downhole component longevity due to a 50% to 150%improvement in erosion performance. These improvements suggest a corresponding increase in operational efficiency by way of a reduced need for frequent trips in and out of hole.

[0035] Although various embodiments have been shown and described, the invention is not so limited and will be understood to include all such modifications and variations as would be apparent to one skilled in the art. Specifically, the erosion-decreasing method disclosed herein may be beneficially employed by pumping the power fluid through the jet pump at a sufficient velocity to cause the power fluid pressure in the area between the nozzle and throat and/or in the throat itself to be less than or equal to the power fluid vapor pressure. Similarly, cavitation vapor bubbles in the power fluid may be created in the area between the nozzle and throat and/or in the throat itself. In addition, the wellbore fluid and power fluid may be mixed while the fluid pressure is less than or equal to the power fluid vapor pressure or shortly before the fluid pressure drops to the power fluid vapor pressure or immediately after the cavitation bubbles of the power fluid are recaptured.